Basic Motor Theory

Introduction

It has been said that if the Ancient Romans, with their advanced civilization and knowledge of the sciences, had been able to develop a steam motor, the course of history would have been much different. The development of the electric motor in modern times has indicated the truth in this theory. The development of the electric motor has given us the most efficient and effective means to do work known to man. Because of the electric motor we have been able to greatly reduce the painstaking toil of man's survival and have been able to build a civilization which is now reaching to the stars. The electric motor is a simple device in principle. It converts electric energy into mechanical energy.

Magnetism

We all know that a permanent magnet will attract and hold metal objects when the object is near or in contact with the magnet. The permanent magnet is able to do this because of its inherent magnetic force that is referred to as a "magnetic field".

In Figure 1 , the magnetic field of two permanent magnets are represented by "lines of flux". These lines of flux help us to visualize the magnetic field of any magnet even though they only represent an invisible phenomena. The number of lines of flux vary from one magnetic field to another. The stronger the magnetic field, the greater the number of lines of flux which are drawn to represent the magnetic field. The lines of flux are drawn with a direction indicated since we should visualize these lines and the magnetic field they represent as having a distinct movement from a N-pole to a S-pole as shown in Figure 1.

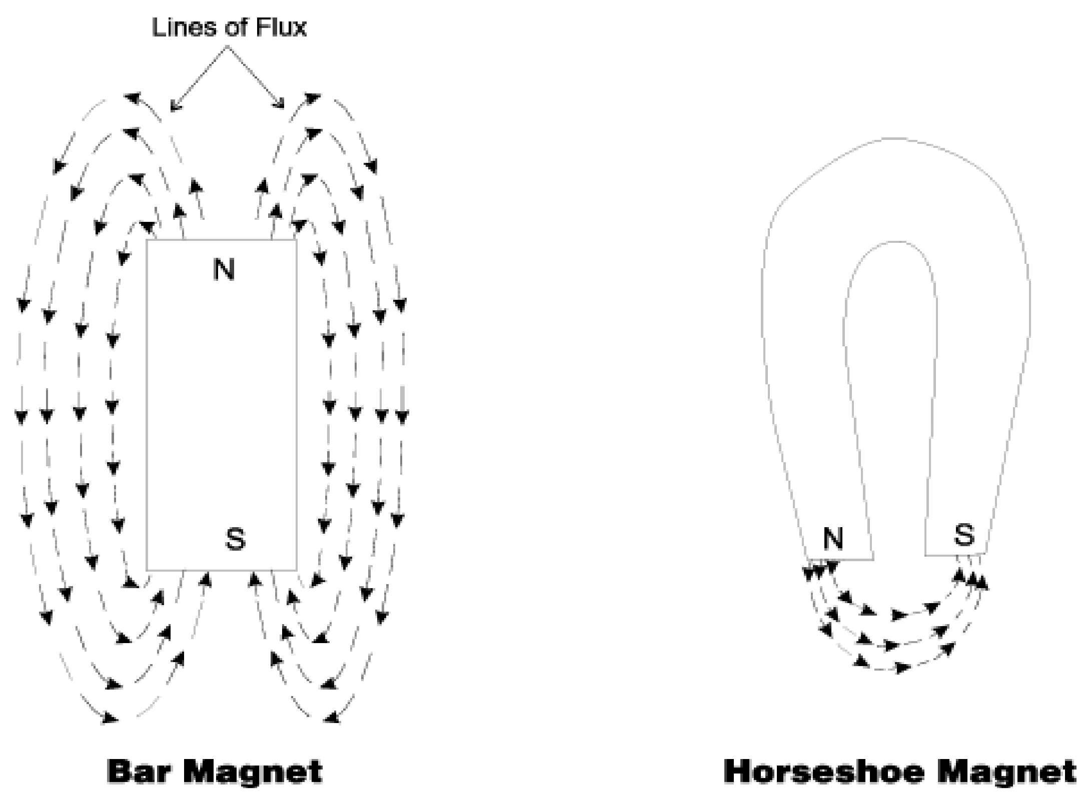


Figure 1

Another but similar type of magnetic field is produced around an electrical conductor when an electric current is passed through the conductor as shown in Figure 2-a. These lines of flux define the magnetic field and are in the form of concentric circles around the wire. You may remember the old "Left Hand Rule" as shown in Figure 2-b. The rule states that if you point the thumb of your left hand in the direction of the current, your fingers will point in the direction of the magnetic field.

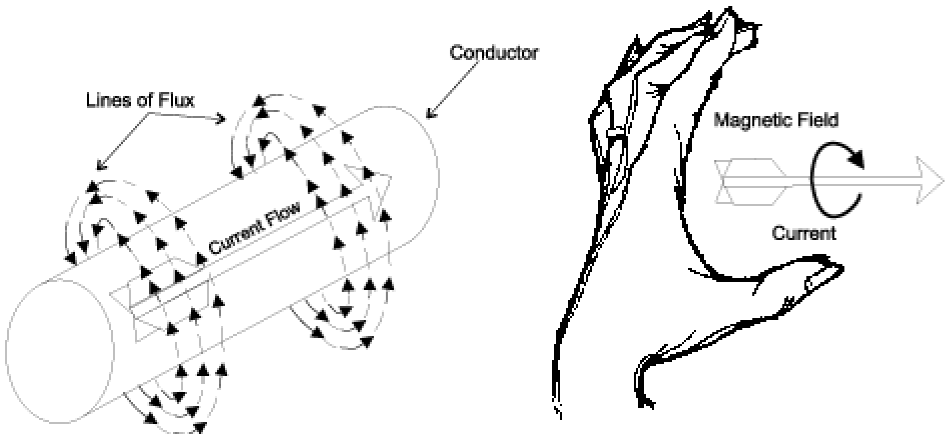


Figure 2

When the wire is shaped into a coil as shown in Figure 3, all the individual flux lines produced by each section of wire join together to form one large magnetic field around the total coil. As with the permanent magnet, these flux lines leave the north of the coil and re-enter the coil at its south pole. The magnetic field of a wire coil is much greater and more localized than the magnetic field around the plain conductor before being formed into a coil. This magnetic field around the coil can be strengthened even more by placing a core of iron or similar metal in the center of the core. The metal core presents less resistance to the lines of flux than the air, thereby causing the field strength to increase. (This is exactly how a stator coil is made; a coil of wire with a steel core.) The advantage of a magnetic field which is produced by a current carrying coil of wire is that when the current is reversed in direction the poles of the magnetic field will switch positions since the lines of flux have changed direction.

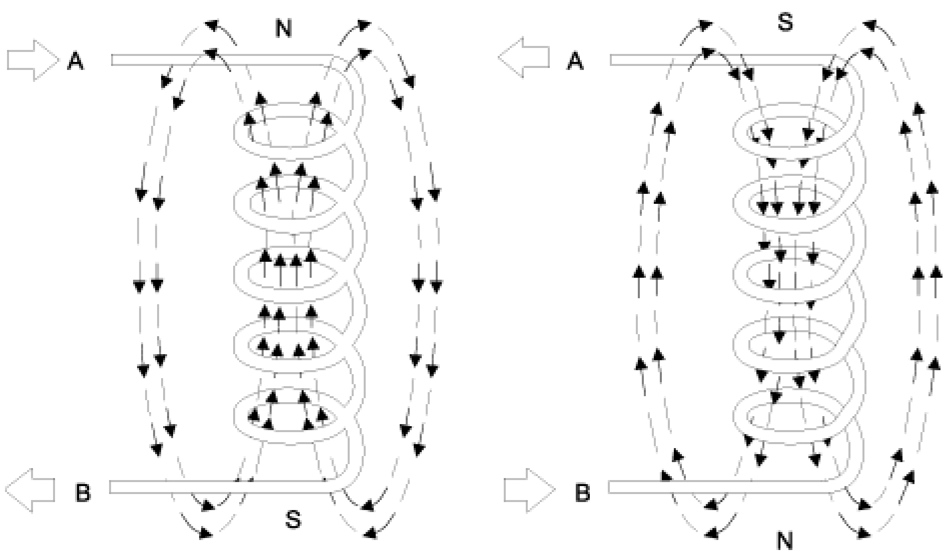


Figure 3

Magnetic Propulsion Within A Motor

The basic principle of all motors can easily be shown using two electromagnets and a permanent magnet. Current is passed through coil no. 1 in such a direction that a north pole is established and through coil no. 2 in such a direction that a south pole is established. A permanent magnet with a north and south pole is the moving part of this simple motor. In Figure 4-a the north pole of the permanent magnet is opposite the north pole of the electromagnet. Similarly, the south poles are opposite each other. Like magnetic poles repel each other, causing the movable permanent magnet to begin to turn. After it turns part way around, the force of attraction between the unlike poles becomes strong enough to keep the permanent magnet rotating. The rotating magnet continues to turn until the unlike poles are lined up. At this point the rotor would normally stop because of the attraction between the unlike poles. (Figure 4-b)

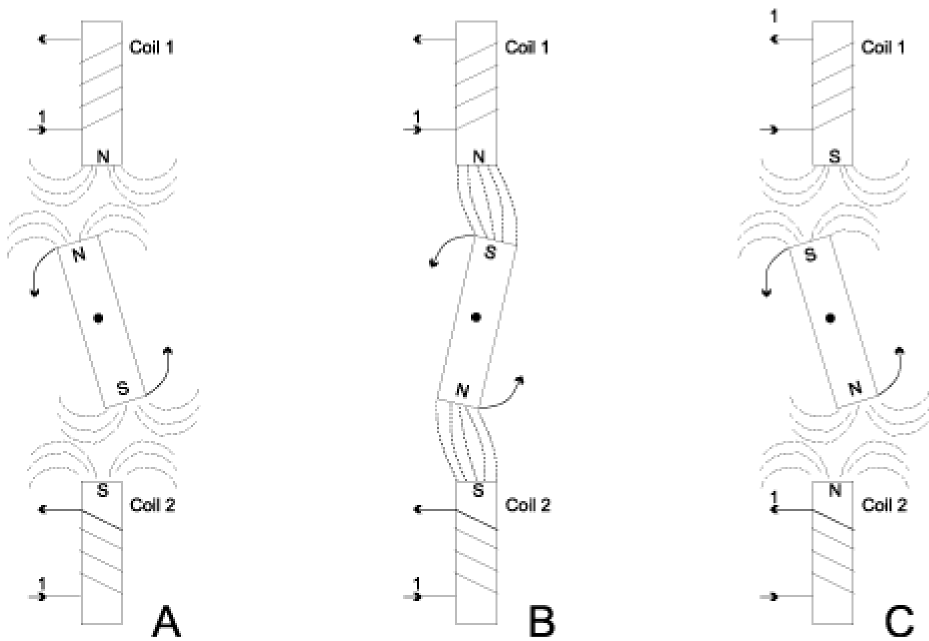


Figure 4

If, however, the direction of currents in the electromagnetic coils was suddenly reversed, thereby reversing the polarity of the two coils, then the poles would again be opposites and repel each other. (Figure 4-c). The movable permanent magnet would then continue to rotate. If the current direction in the electromagnetic coils was changed every time the magnet turned 180 degrees or halfway around,then the magnet would continue to rotate. This simple device is a motor in its simplest form. An actual motor is more complex than the simple device shown above, but the principle is the same.

DC Motor General Construction

A typical PMDC motor consists of: An armature stack and winding, an air gap, permanent magnets which form the magnetic circuit; brushes and a commutator which form the electric circuit; a frame, end bells, bearings, brush supports and a shaft which provide the mechanical support. See figure on next page.

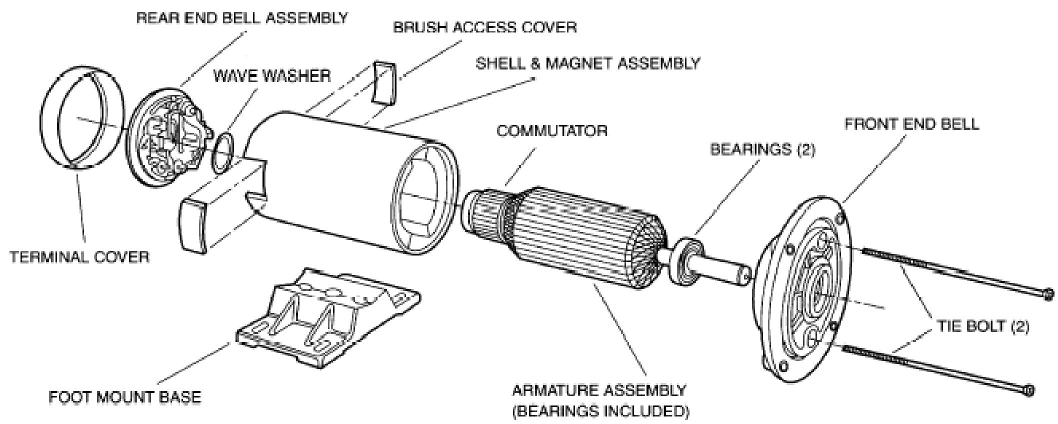


Figure 1 Exploded View

Armature Core or Stack
The armature stack is made up thin magnetic steel laminations stamped from sheet steel with a blanking die. Slots are punched in the lamination with a slot die. Sometimes these two operations are done as one. The laminations pressed together.

Armature Winding
The armature winding is the winding, which fits in the armature slots and is eventually connected to the commutator. It either generates or receives the voltage depending on whether the unit is a generator or motor. The armature winding consists of copper wire and is insulated from the armature stack.

Magnets
The magnets are made of Ceramic material and are attached to the housing using air dry adhesive. Two magnets are used in each motor

Yoke
The yoke is a circular steel ring, which supports the field, poles mechanically and provides the necessary magnetic path between the pole. The yoke can be solid or laminated. In many DC machines, the yoke also serves as the frame.

Commutator
The commutator is the mechanical rectifier, which changes the AC voltage of the rotating conductors to DC voltage. It consists of a number of segments normally equal to the number of slots. The segments or commutator bars are made of silver bearing copper and are separated from each other by mica insulation.

Brushes and Brush Holders
Brushes conduct the current from the commutator to the external circuit. There are many types of brushes. A brush holder is usually a metal box that is rectangular in shape. The brush holder has a spring that holds the brush in contact with the commutator. Each brush has a flexible copper shunt or pigtail, which extends to the lead wires.

Frame, End Bells, Shaft, and Bearings
The frame is steel and the end bells are aluminum castings and are used to enclose and support the basic machine parts. The armature is mounted on a steel shaft, which is supported between two bearings. The bearings are ball type.

Lap Winding

When the end connections of the coils are brought to adjacent bars as shown in Figure 5, a lap or parallel winding is formed.

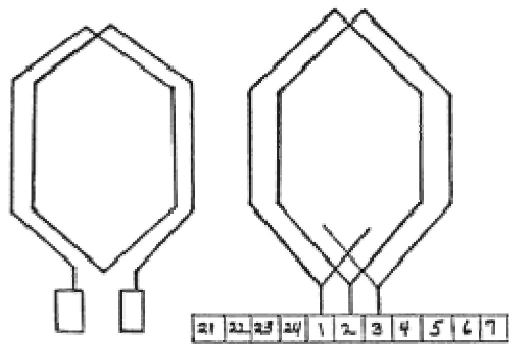


Figure 5

Lap Winding connected to commutator bars

Any winding can be illustrated in one of two forms, the circular form or the development form. A simplex lap winding in circular form is shown in Figure 6. In this particular circular form, the flux cutting portions of the conductors are shown as straight lines radiating from the center and are numbered for convenience in connecting them to the commutator which is in the center of the diagram. The outermost connecting lines represent the end connections on the back of the armature and the inner connecting lines represent the connections on the front or commutator end of the armature.

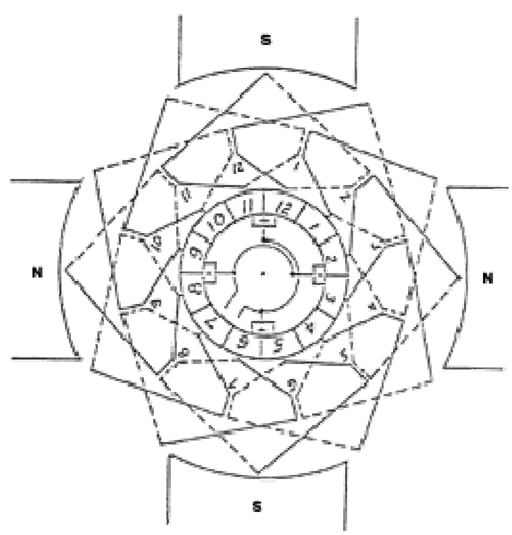


Figure 6

Simplex Lap Winding, Circular Form

The development form of winding (Figure 7) represents the armature as if it were split open and rolled out flat. It is somewhat simpler to understand but the continuity of the winding is broken. The lap winding is best suited for low voltage, high current ratings because of the number of parallel paths.

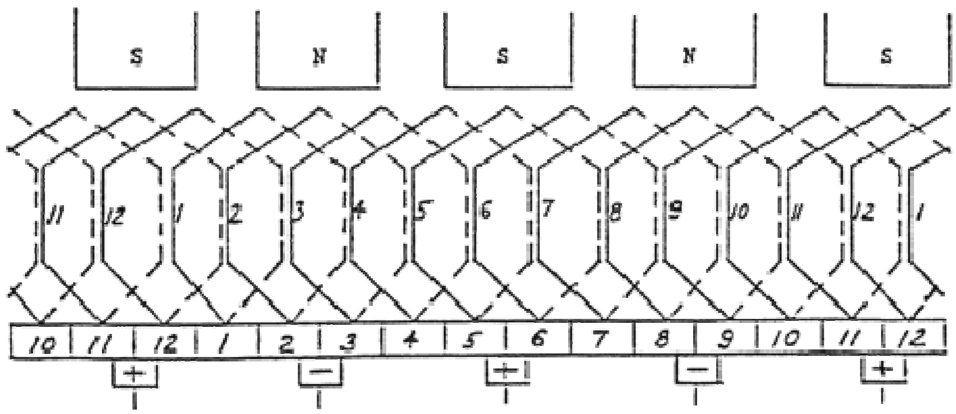
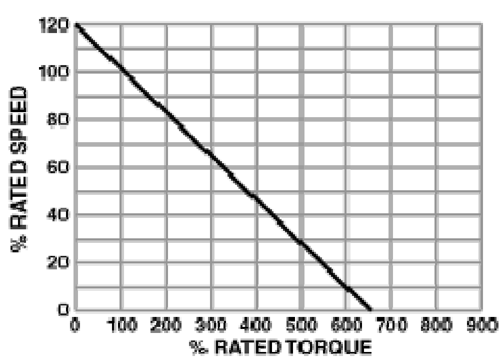
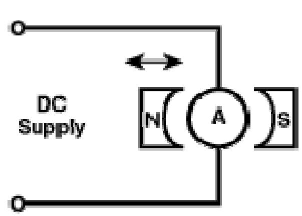


Figure 7.
Simplex Lap Winding, Development Form

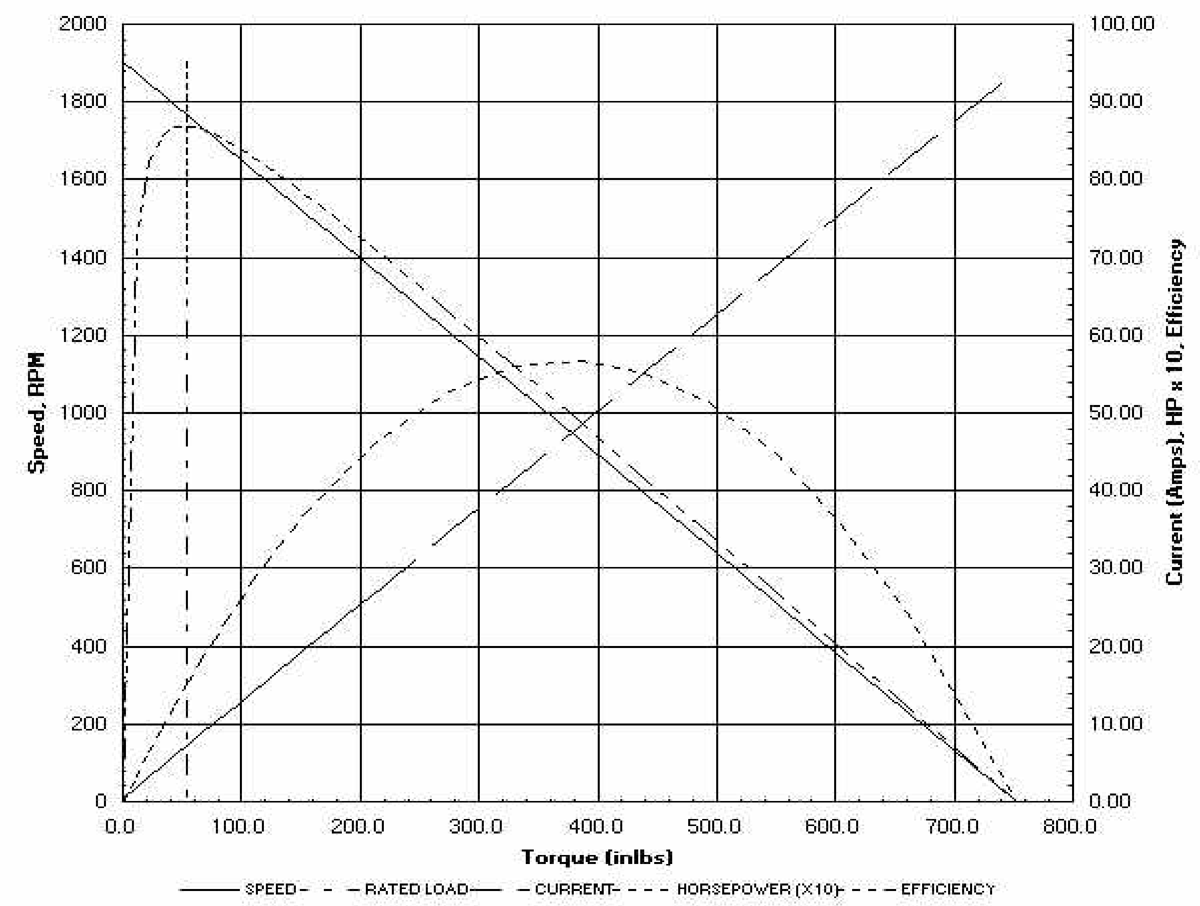
Slots and Coils
Pacific Scientific PMDC motor has 28 slots. On motors made for 130 VDC and below we use 28 coils. On motors above 130 VDC we use 56 coils, meaning there are two coils per slot. .

Typical Speed - Torque Curve
Permanent magnet motors have no wound field and a conventional wound armature with commutator and brushes. This motor has excellent starting torques. Because of permanent field, motor losses are less with better operating efficiencies. These motors can be dynamically braked and reversed at some low armature voltage (10%) but should not be plug reversed with full armature voltage. Reversing current can be no higher than the locked armature current.





SPEED TORQUE CURVE



PACIFIC SCIENTIFIC PMDC MOTOR FEATURE SET